



Ministère des Ressources naturelles
Natural Resources Canada

CANMET

Centre de recherche en métallurgie
Research Centre in Metallurgy
4675, boulevard de l'Université
Ottawa, Ontario K1A 0S6



Ontario



CATALOGUE OF ROCKBURST LITERATURE

MRL 87-50 LS

88-00472/

CATALOGUE OF ROCKBURST LITERATURE

D.G.F. HEDLEY

ELLIOT LAKE LABORATORY

January 1987

MICROMEDIA

This document is a summary
of the literature on rockbursts
published between 1970 and 1986
in the English language
concerning the physical and
mechanical aspects of the problem
for Mining and Energy Technology
(CANMET)

Ce document est un résumé
des publications relatives aux
éclatements de roches publiées
entre 1970 et 1986 en langue
anglaise concernant les aspects
physiques et mécaniques du
problème pour les mines et
l'énergie (CANMET)

35/90

MINING RESEARCH LABORATORIES

DIVISIONAL REPORT MRL 87-50 (LS)

CATALOGUE OF ROCKBURST LITERATURE

by

D.G.F. Hedley*

ABSTRACT

During the last century rockbursts have become a serious problem in deep hard rock mines. They have caused numerous fatalities and injuries, mine closures and abandonment of ore reserves. Scientific research to reduce the rockburst hazard has been undertaken in many countries including, South Africa, Canada, United States and India. Over 200 papers in the English language press are listed and categorized in this catalogue.

This report is a draft chapter of a "Rockburst Handbook for Canadian Hardrock Mines" being produced under the Canada/Ontario/Industry Rockburst Project.

Key words: Rockbursts; Seismology; Microseismic monitoring; Bibliography.

*Senior Research Scientist, Elliot Lake Laboratory, Energy, Mines and Resources Canada, Elliot Lake, Ontario.

CATALOGUE DE LITTÉRATURE SUR LES COUPS DE TOIT

par

D.G.F. Hedley *

RÉSUMÉ

Depuis les cent dernières années, les coups de toit posent de sérieux problèmes dans les mines de roche dure profondes. Ces coups de toit sont la cause entre autres de nombreux accidents mortels, de blessures, de fermeture de mines et enfin, de l'abandon de gisements de minerais. Par conséquent, plusieurs pays dont l'Afrique du Sud, le Canada, les États-Unis et l'Inde font de la recherche scientifique dans le but de réduire les dangers de coups de toit. Le catalogue contiendra plus de 200 rapports publiés en langue anglaise et classés par catégorie.

Le présent rapport est un brouillon de l'un des chapitres du manuel sur les coups de toit dans les mines de roche dure au Canada "Rockburst Handbook for Canadian Hardrock Mines" préparé dans le cadre du projet de recherche conjoint Canada/Ontario/Industrie sur les coups de toit.

MOTS-CLÉS: Coups de toit; séismologie; surveillance microsismique; bibliographie.

*Chercheur scientifique principal, Laboratoire d'Elliot Lake, Énergie, Mines et Ressources Canada, Elliot Lake, Ontario

INTRODUCTION

Although mining has been carried out for at least a couple of millenia, rockbursts have occurred only over the last century. Improvements in mining technology, especially in explosives, hoisting, pumping and ventilation, allowed mines to go deeper into an ever increasing stress environment. Scientific articles on rockbursts are even more recent and are mainly confined to the last thirty years.

In this review only readily available English literature has been consulted, and only in respect to hard rock mines (i.e., coal and potash mines are not covered). Consequently, most of the literature is concerned with South African gold mines, metal mines in Northern Ontario, Canada, the Kolar Gold Fields in India, and the Coeur d'Alene mining district in Idaho, United States.

About 200 articles in the literature have been divided into several categories as follows:

- a) General reviews and text books.
- b) Rockburst mechanics.
- c) Seismic monitoring and source location.
- d) Rockburst seismology.
- e) Rockburst alleviation.
- f) Controlling rockburst damage and destressing.
- g) Rockburst prediction.
- h) Case histories.

For each category the literature is listed chronologically, then alphabetically within each year.

There have been a number of symposia dealing exclusively with rockbursts and seismic activity. The most noteworthy are as follows:

Rockbursts and Seismicity in Mines, Johannesburg, 1982. Published by the South African Institute of Mining and Metallurgy, Symposium Series No. 6, 1984.

Rockbursts: Prediction and Control, London, 1983. Published by The Institute of Mining and Metallurgy.

Conferences on Acoustic Emission/Microseismic Activity in Geologic Structures and Materials, Pennsylvania State University, 1st Conference (1975), 2nd (1978), 3rd (1981), 4th (1985). Published by Trans Tech Publications.

GENERAL REVIEWS AND TEXT BOOKS

The first known study on rockbursts was by a committee, appointed by the South African Government in 1908, to investigate tremors being felt on surface. This committee established that the tremors were not naturally occurring (i.e., earthquakes), but were caused by mining operations and specifically the 'shattering of support pillars'. Subsequent government committees were appointed in 1915, 1924 and 1964 to study the ever increasing rockburst incidents in South African gold mines. In 1977, a high-level committee appointed by the South African Chamber of Mines reviewed the findings of these earlier committees, as well as presenting the latest state-of-the-art for reducing the rockburst hazard. Additional overviews have been published in recent years.

Rockbursts on the Kolar Gold Fields in India started at about the same time as those in South Africa. Much of the information was published in a local mining society, but more readily available reviews on rockburst research have been published at regular intervals in recent years (1963, 1972, and 1983).

Rockbursts in Ontario mines started during the 1930's, mainly in the

Sudbury and Kirkland Lake mining camps. The Ontario Mining Association set up an industry rockburst committee in the mid-1930's which was active until the late-1940's. This committee retained R.G.K. Morrison to report on the rockburst situation in Ontario mines in the early 1940's. With the closure of many of the rockburst prone mines the problem decreased. However, in the 1980's the problem reappeared with significant rockburst activity in Red Lake, Elliot Lake, Sudbury and Kirkland Lake mines. An Ontario provincial inquiry was commissioned in 1984 to investigate the problem. In 1985 a tripartite rockburst research project was initiated between the governments of Canada and Ontario and the Ontario Mining Association.

In the United States, rockbursts have been experienced in two regions; the copper mines in northern Michigan (now closed), and in the Coeur d'Alene district of Idaho. The mines in Idaho have been the subject of many field trials by the United States Bureau of Mines, universities, consultants and mining companies, involving microseismic monitoring, destressing and rock pre-conditioning.

A number of rock mechanics text books contain chapters specifically on rockbursts. The earlier text books were mainly descriptive of the mining conditions favouring rockburst incidents and methods of reducing the hazard. Those by Jaeger and Cook, and by Salamon, incorporate the theory of elasticity, stiffness concepts and an energy balance approach to explain rockburst occurrences.

OVERVIEWS OF ROCKBURST OCCURRENCES

Morrison, R.G.K., (1942), Report on the rockburst situation in Ontario mines; Trans. CIM, vol. 45, pp 225-272.

Taylor, J.T.M., (1963), Research on ground control and rockbursts on the Kolar Gold Field, India; Trans. IMM, vol. 72, pp. 317-338

- Cook, N.G.W., Hoek, E., Pretorius, J.P.G., Ortlepp, W.D. and Salamon, M.D.G., (1966), Rock mechanics applied to the study of rockbursts; J. S. African Inst. Min. Met., vol. 66, pp. 435-528.
- Blake, W., (1972), Rock-burst mechanics; Colorado School of Mines Quarterly, vol. 67, No. 1, pp. 1-64.
- Krishna Murthy, R., (1972), A review of rockburst research in the Kolar Gold Fields; Symp. on Rock Mechanics - Theory and Practice, Dhanbad, India.
- High Level Committee, (1977), An industrial guide to the amelioration of the hazard of rockbursts and rock falls; Research Organization, Chamber of Mines of South Africa, 178 p.
- Ortlepp, W.D., (1982), Rockbursts in South African gold mines: a phenomenological view; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 165-178.
- Dempster, E.L., Tyser, J.A. and Wagner, H., (1983), Regional aspects of mining-induced seismicity: theoretical and management considerations; Rockbursts: Prediction and Control, IMM, London, pp. 37-52.
- Krishna Murthy, R. and Gupta, P.D., (1983), Rock mechanics studies on the problem of ground control and rockbursts in the Kolar Gold Fields; Rockbursts: Prediction and Control, IMM, London, pp. 67-80.
- Hedley, G.D.F., and Wetmiller, R.J., (1985), Rockbursts in Ontario mines during 1984; CANMET Report SP85-5, Energy, Mines and Resources Canada, 36 p.
- Provincial Inquiry into Ground Control and Emergency Preparedness in Ontario Mines, (1986), Improving ground stability and mine rescue; Publication Services, Ontario Government, 107 p.

ROCK MECHANICS TEXT BOOKS WITH CHAPTERS ON ROCKBURSTS

Isaacson, E. de St. Q., (1958). Rock pressure in mines; Mining Publications Ltd., London.

Woodruff, S.D., (1966), Methods of working coal and metal mines; Pergamon Press.

Obert, L. and Duvall, W.I., (1967), Rock mechanics and the design of structures in rock; John Wiley and Sons, New York.

Jaeger, J.C. and Cook, N.G.W., (1969), Fundamentals of rock mechanics; Methuen, London.

Salamon, M.D.G., (1974), Rock mechanics of underground excavations; Proc. 3rd Cong. Int. Soc. Rock Mech., Denver, Colorado, vol. 1, Part B, pp 951-1099.

Morrison, R.G.K., (1976), A philosophy of ground control; Revised Edition, McGill University, Montreal.

Budavari, S., Editor (1983), Rock mechanics in mining practice; S. Afr. Inst. Min. Met., Monograph Series No. 5.

ROCKBURST MECHANICS

Prior to the 1950's a traditional engineering approach of observation, experience and trial-and-error methods was used to combat the rockburst hazard. Since that time scientific research has been used in an attempt to understand the causes and mechanisms of rockbursts. First the theory of elasticity was applied, for simple geometries, to estimate the redistribution of stress as a result of mining.

In the 1960's three important advances were made, notably by N.G.W. Cook. The first multi-channel microseismic monitoring system was installed in a South African gold mine. This system gave relatively accurate locations for

both small and large seismic events. An energy balance approach was used to evaluate the source of energy liberated in a rockburst. All sources of energy entering the system as a result of mining were balanced against how the energy could be dissipated. The excess energy would be liberated as seismic energy. It was also discovered that the post-failure behaviour of brittle rock was either violent or non-violent depending on the stiffness of the loading machine.

The concepts of an energy balance and pillar stiffness versus loading stiffness were further refined by Salamon in a number of publications. Computer models incorporating energy and stiffness concepts were developed soon after.

In recent years research has been concerned with the mechanisms involved with various types of rockbursts. This has included the fracture patterns around longwall faces and shearing through intact rock (i.e., development of new faults) in South Africa. In Canada attention has been focused on pillar bursts that are occurring in the Elliot Lake, Red Lake and Kirkland Lake mines, and the fault-slip type bursts that are occurring in mines at Sudbury.

ROCKBURST MECHANICS

Hill, F.G., (1954), An investigation into the problems of rock bursts; J. South African Inst. Min. Met., vol. 55, pp. 63-102.

Coates, D.F., (1959), Energy released in rockbursts; Colorado School of Mines Quarterly, vol. 54, No. 3.

Cook, N.G.W., (1963), The basic mechanics of rockbursts; J. S. Afr. Inst. Min. Met, vol. 64, pp. 71-81.

- Cook, N.G.W., (1965), The failure of rock; Int. J. Rock Mech Min. Sci., vol. 2, pp. 389-403.
- Cook, N.G.W., (1965), A note on rockbursts considered as a problem of stability; J. S. Afr. Inst. Min. Met., vol. 65, pp. 437-446.
- Deist, F.H., (1965), A non-linear continuum approach to the problem of fracture zones and rockbursts; J. S. Afr. Inst. Min. Met, 65, pp. 502-522.
- Duvall, W.I. and Stephenson, D.F., (1965), Seismic energy available from rockbursts and underground explosions; Trans. AIME, pp. 235-240.
- Cook, N.G.W., Hoek, E., Pretorius, J.P.G., Ortlepp, W.D. and Salamon, M.D.G., (1966), Rock mechanics applied to the study of rockbursts; J. S. Afr. Inst. Min. Met, vol 66, pp. 435-528.
- Cook, N.G.W., (1967), Design of underground excavations; 8th U.S. Rock Mech. Symp., Minnesota, pp. 167-193.
- Salamon, M.D.G., (1968), Two-dimensional treatment of problems arising from mining tabular deposits in isotropic or transversely isotropic ground; Int. J. Rock Mech. Min. Sci., vol. 5, No. 2, pp. 159-185.
- Starfield, A.M. and Fairhurst, C., (1968), How high-speed computers can advance design of practical mine pillar systems; Eng. & Min. J., vol. 169, pp. 78-84.
- Blake, W., (1972), Rock-burst mechanics; Colorado School of Mines Quarterly, vol. 67, No. 1, pp. 1-64.
- Salamon, M.D.G., (1974), Rock mechanics of underground excavations; Proc. 3rd Cong. Int. Soc. Rock Mech., Denver, Colorado, Vol. 1B, pp. 951-1099.
- Crouch, S.L., (1974), Analysis of rock bursts in cut-and-fill stopes; Trans. SME-AIME, vol. 256, pp. 298-303.

- Walsh, J.B., (1977), Energy changes due to mining; Int. J. Rock Mech. Min. Sci. & Geomech. Abst., vol. 14, pp. 25-33.
- Ortlepp, W.D., (1978), The mechanism of a rockburst; 19th U.S. Rock Mech. Symp., Reno, Nevada.
- Crouch, S.L., (1979), Computer simulation of mining in faulted ground; J. S. Afr. Inst. Min. Met., vol 79, pp. 159-173.
- Brady, B.H.G. and Brown, E.T., (1981), Energy changes and stability in underground mining: design application of boundary element methods; Trans IMM, vol. 90, Sect. A, pp. 61-68.
- Gibowicz, S.J., (1982), The mechanism of large mining tremors in Poland; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 17-28.
- Cook, N.G.W., (1983), Origin of rockbursts; Rockbursts: Prediction and Control, IMM, London, pp. 1-10.
- Joughin, N.C. and Jager, A.J., (1983), Fracture of rock at stope faces in South African gold mines; Rockbursts: Prediction and Control, IMM, London, pp. 53-66.
- Salamon, M.D.G., (1983), Rockburst hazard and the fight for its alleviation in South African gold mines; Rockbursts: Prediction and Control, IMM, London, pp. 11-36.
- Zubelewics, A. and Mroz, Z., (1983), Numerical simulation of rock burst processes treated as problems of dynamic instability; Rock Mech. & Rock Eng., vol. 16, pp. 253-274.
- Hedley, D.G.F., Roxburgh, R.W. and Muppalaneni, S.N., (1984), A case history of rockbursts at Elliot Lake; 2nd Int. Conf. Stability in Underground Mines, Lexington, Kentucky.

Salamon M.D.G., (1984), Energy considerations in rock mechanics: fundamental results; J. S. Afr. Inst. Min. Met., vol. 84, No. 8, pp. 233-246.

Hedley, D.G.F., Bharti, S., West, D. and Blake, W., (1985), Fault-slip rockbursts at Falconbridge Mine; 4th Conf. Acoustic Emission/Microseismic Activity, Penn. State University.

Swan, G., (1985), Multiple pillar compression failure in brittle rock; Division Report MRP/MRL 85-103(TR), CANMET, Energy, Mines and Resources Canada.

SEISMIC MONITORING AND SOURCE LOCATION

The first single channel microseismic system was developed by the United States Bureau of Mines in the early 1940's and tested in both United States and Canadian mines. The number of microseismic events in a given time was the main parameter, which was subject to equipment noise problems.

Apparently, the first multi-channel microseismic system was used by N.G.W. Cook in a South African gold mine in the early 1960's. This system gave source location and a measure of the seismic energy liberated. Additional microseismic systems were installed in South African gold mines, followed by mines in the Coeur d'Alene, United States, in the 1970's and Canadian mines in the 1980's. The commercially available Electrolab system, with up to 64 channels, is used predominantly in North American mines.

Regional seismic networks have also been installed in South African mining areas. These systems have widely spaced geophones covering several mines and are used for detection and source location of the major rockbursts.

A number of source location techniques have been developed. Most use the arrival times of the compression wave to successive geophones. The so-called 'direct solution' uses a series of linear equations to solve for the three-dimensional coordinate plus the velocity. Least squared versions of

this method have been developed by the United States Bureau of Mines and Mt. Isa in Australia. The so-called 'block' and 'simplex' methods use a series of non-linear equations. When the complete seismic waveform is recorded the separation of the compression and shear waves is used to calculate source location. A number of papers have been published comparing the accuracy of the various methods.

SEISMIC MONITORING AND SOURCE LOCATION METHODS

Obert, L. and Duvall, W.I., (1957), Microseismic method of determining the stability of underground openings; U.S. Bureau of Mines Bull. 573.

Cook, N.G.W., (1963), The seismic location of rockbursts; Proc. 5th U.S. Rock Mech. Symp., Minnesota, pp. 493-516.

Cook, N.W.G., (1964), The application of seismic techniques to problems in rock mechanics; Int. J. Rock Mech. Min Sci., vol. 1, No. 2, pp. 169-179.

Blake, W. and Leighton, F.W., (1970), Recent developments and application of the microseismic method in deep mines; Rock Mechanics - Theory and Practice, AIME, pp. 429-443.

Leighton, F.W. and Duvall, W.I., (1972), A least squares method for improving rock noise source location techniques; U.S. Bureau of Mines, RI 7626.

Blake, W., Leighton, F.W. and Duvall, W.I., (1974), Microseismic techniques for monitoring the behaviour of rock structures, U.S. Bureau of Mines, Bull. 665.

Longstaff, J.T., (1974), Seismic detection system at Lucky Friday mine; World Mining, October 1974, pp. 58-61.

Salamon, M.D.G. and Wiebols, G.A., (1974), Digital location of seismic events by an underground network of seismometers using arrival times of compression waves; Rock Mechanics, vol. 6, pp. 141-166.

- Blake, W., (1975), Design, installation and operation of computer controlled rock burst monitoring systems; 1st Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Mowrey, G.L., (1975), Computer processing and analysis of microseismic data, 1st Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Longstaff, J.T., (1977), Hecla's rock burst monitoring system; Min. Congr. J. Jan. 1977, pp. 46-51.
- Berezniak, J.M., (1978), Application of radio telemetry systems in microseismic field studies; 2nd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Blake, W., (1978), Evaluating data from rock burst monitoring systems using energy of microseismic events; 2nd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Godson, R.A., Bridges, M.C. and McKavanagh, B.M., (1978), A 32-channel rock noise source location system; 2nd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Leighton, F.W., (1978), Microseismic studies at the Henderson Mine; 2nd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Atkins, A.R., Pattrick, K.W., Rorke, A. and Roering, C., (1981), The design and use of a small and a microseismic network for studying the mechanism of rock fracture in deep level mines; 3rd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Bourbonnais, J., (1981), A research application of multi-channel microseismic monitoring to rock bursting at the East Malartic Mine in Northwestern Quebec; 3rd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.

- Malott, C., (1981), Theoretical limitations of microseismic transducer systems; 3rd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Pakalnis, V., (1981), Strengths and limitations of microseismic monitoring for rockburst control in Ontario mines; 3rd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Rindorf, H.J., (1981), Location of microseismic activity; 3rd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Rowell, G.A. and Yoder, L.P., (1981), The effect of geophone emplacement on the observed frequency content of microseismic signals; 3rd Conf. Acoustic Emission/Microseismic Activity, Penn State University.
- Blake, W., (1982), Microseismic applications for mining - a practical guide; U.S. Bureau of Mines Contract Report J0215002.
- Blake, W., (1982), Design considerations for seismic monitoring systems; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met Symp. Series No. 6, pp. 79-82.
- Eccles, C.D. and Ryder, J.A., (1982), Seismic location algorithms: a comparative evaluation; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met Symp. Series No. 6, pp. 89-92.
- Green, R.W.E., (1982), Design considerations for an underground seismic network; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 67-74.
- Hardy, H.R., (1982), Stability monitoring of underground structures using acoustic emission techniques; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 277-286.
- Lawrence, D.A., (1982), Seismicity in the Orange Free State gold mining district; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 121-130.

- Patrick, K.W., (1982), The instrumentation of seismic networks at Doornfontein Gold Mine; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met Symp. Series No. 6, pp. 337-340.
- Scheepers, J.B., (1982), The Klerksdorp seismic network - monitoring of seismic events and systems layout; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met Symp. Series No. 6, pp. 341-346.
- Spottiswoode, S.M., (1982), Management applications of mine seismicity studies; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 347-348.
- Van Der Heever, P.K., (1982), Some technical and research aspects of the Klerksdorp seismic network; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 349-350.
- Batchelor, A.S., Baria, R. and Hearn, K., (1983), Microseismic detection for Camborne Geothermal project; Rockbursts: Prediction and Control, IMM, London, pp. 147-160.
- MacDonald, P. and Muppalaneni, S.N., (1983), Microseismic monitoring in a uranium mine; Rockbursts: Prediction and Control, IMM, London, pp. 141-146.
- Davidge, G.R., (1984), Microseismic monitoring at Falconbridge Mine, Falconbridge, Ontario; CIM Bull., vol. 77, No. 868, pp. 45-49.
- Neumann, M. and Makuch, A., (1984), Case study of microseismic monitoring of the 'F-2' zone at Campbell Red Lake Mines Limited; Workshop Microseismic Monitoring in Canadian Mines, Sudbury. Division Report MRP/MRL 85-23, CANMET, Energy, Mines and Resources Canada.
- Gendzwill, D.J. and Prugger, A.F., (1985), Some new algorithms for micro-earthquake locations; 4th Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Neumann, M., (1985), Microseismic monitoring at Campbell Red Lake Mines Ltd;

45th Annual Meeting, Mines Accident Prevention Assoc. of Ontario, Toronto.

Oliver, P.H. and MacDonald, P., (1985), The microseismic monitoring system at Creighton Mine, INCO Ltd; 4th Conf. Acoustic Emission/Microseismic Activity, Penn. State University.

ROCKBURST SEISMOLOGY

Scientific observations on earthquakes has taken place over a much longer time period than rockbursts, consequently literature on seismology is much more vast. Only those papers on seismology which have a direct application to mining or involving source location techniques have been reviewed.

Rockburst magnitude scales are the same as those used for earthquakes. Most countries use a local magnitude scale developed by Richter, except for eastern North America, where a scale developed by Nuttli is used. However, Hasegawa has developed a relationship between the two scales for the Canadian Shield.

Comprehensive reviews on the application of seismology methods of analysis to rockbursts and mining related problems have been presented at two rock mechanics conferences: by A. Nur in Denver in 1974, and by M. Bath in Johannesburg in 1982.

One of the first applications of seismology techniques to rockbursts was by E. Hodgson in the Kirkland Lake mining camp, Ontario during the 1930's to 1940's. Since that time most of the investigations have been carried out in the South African gold mines, notably by A. McGarr and S.M. Spottiswoode.

ROCKBURST SEISMOLOGY

Hodgson, E.A., (1943), Recent developments in rock burst research at Lake Shore Mines; Trans. CIM, vol. 46.

- Hodgson, E.A. (1958), Dominion Observatory rockburst research 1938-1945; Publication Dominion Observatory, vol. 20, No. 1, Ottawa, p. 248.
- Richter, C.F., (1958), Elementary seismology; W.H. Freeman, San Francisco.
- Brune, J.N., (1970), Tectonic stress and the spectra of seismic shear waves from earthquakes; J. Geophys Res, vol. 75, pp. 4997-5009. Correction: J. Geophys Res., vol. 76, (1971), p. 5002.
- McGarr, A., (1971), Violent deformation of rock near deep-level tabular excavations - seismic events; Bull. Seis. Soc. Am., vol. 61, No. 5, pp. 1453-1466.
- McGarr, A., (1971), Stable deformation of rock near deep-level tabular excavations; J. Geophys. Res., vol. 76, pp 7088-7106.
- Jackson, D.D., (1972), Interpretation of inaccurate, insufficient and inconsistent data; Geophys. J. Roy. Astr. Soc. No. 28, pp. 97-109.
- Wiggins, R.A., (1972), The general inverse problems: implication of surface waves and free oscillations for earth structure; Rev. Geophys. Space Phys. vol. 10, pp. 251-285.
- Nuttli, O.W., (1973), Seismic wave attenuation and magnitude relations for eastern North America; J. Geophys. Res., vol. 78, pp. 876-885.
- Nur, A., (1974), Tectonophysics: the study of relations between deformation and forces in the earth; 3rd Congr. Int. Soc. Rock Mech., Denver, Colorado, vol. 1, Part A, pp. 243-318.
- McGarr, A., Spottiswoode, S.M. and Gay, N.C., (1975), Relationship of mine tremors to induced stresses and to rock properties in the focal region; Bull. Seis. Soc. Am., vol. 65, pp. 981-993.
- Spottiswoode, S.M. and McGarr, A., (1975), Source parameters of tremors in a deep-level gold mine; Bull. Seis. Soc. Am., vol. 65, No. 1, pp. 93-112.

- McGarr, A., (1976), Seismic moments and volume change; *J. Geophys. Res.*, vol. 81, No. 8, pp. 1487-1494.
- McGarr, A. and Wiebols, G.A., (1977), Influence of mine geometry and closure volume on seismicity in a deep-level mine; *Int. J. Rock Mech. Min Sci. & Geomech. Abst.*, vol. 14, pp. 139-145.
- McGarr, A. and Green, R.W.E., (1978), Microtremor sequences and tilting in a deep mine; *Bull. Seis. Soc. Am.*, vol. 68, pp. 1679-1697.
- Gay, N.C. and Ortlepp, W.D., (1979), The anatomy of a mining-induced fault zone; *Bull. Geol. Soc. Am.*, vol. 90, pp. 47-58.
- Herrman, R.B., (1979), FASTHYPO - A hypocentre location program, *Earthquake Notes*, vol. 50, pp. 25-37.
- Lee, W.H.K. and Stewart, S.W., (1981), Principle and implications of microearthquake networks; *Advance in Geophysics*, Academic Press, New York.
- McGarr, A., Green, R.W.E. and Spottiswoode, S.M., (1981), Strong motion of mine tremors: some implications for near-source ground motion parameters; *Bull. Seis. Soc. Am.*, vol. 71, pp. 295-319.
- McGarr, A., (1981), Analysis of peak ground motion in terms of a model of inhomogeneous faulting; *J. Geophys. Res.*, vol. 86, pp. 3901-3912.
- Spottiswoode, S.M., (1981), Seismic deformation around Blyvooruitzicht Gold Mine; 3rd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.
- Anderson, K.R., (1982), Robust earthquake location using M-estimates; *Phys. Earth Planet Interiors*, vol. 30, pp. 119-130.
- Bath, M., (1982), Rockburst seismology; *Rockbursts and Seismicity in Mines*, Johannesburg, S. Afr. Inst. Min. Met Symp. Series No. 6, pp. 7-16.

- Hank, T.C., (1982), *arms* and seismic source studies; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 39-44.
- McGarr, A., (1982), Some applications of seismic source mechanism studies to assessing underground hazard; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 199-208.
- McGarr, A., (1982), Upper bounds on near-source peak ground motion based on a model of inhomogeneous faulting; Bull. Seis. Soc. Am., vol. 72, pp. 1825-1841.
- Potgieter, G.J. and Roering, C., (1982), The influence of geology on the mechanisms of mining-associated seismicity in the Klerksdorp Goldfield; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 45-50.
- Rice, J. (1982), Shear instability in relation to constitutive description of fault slip; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 57-62.
- Rorke, A.J. and Roering, C., (1982), Source mechanism studies of mining-induced seismic events in a deep level gold mine; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 51-56.
- Smith, E.G.C., (1982), An efficient algorithm for routine joint hypocentre determination; Geophys. J. Roy. Astr. Soc. No. 19, pp. 165-181.
- Spottiswoode, S.M., (1982), Source mechanisms of mine tremors at Blyvooruitzicht Gold Mine; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 28-38.
- Hasegawa, H.S., (1983), Lg spectra of local earthquakes recorded by the Eastern Canada telemetered network and spectral scaling; Bull. Seis. Soc. Am., vol. 73, No. 4, pp. 1041-1061.

McGarr, A., (1984). Scaling of ground motion parameters, state of stress and focal depth; J. Geophys. Res., vol. 89.

ROCKBURST ALLEVIATION

There are two approaches to the alleviation of rockbursts, which can be termed 'strategic' and 'tactical'. The strategic approach is to diminish the possibility of encountering rockburst-prone ground or to diminish the severity of the rockbursts. Many of the recommendations of the early committees in South Africa and Canada were along these lines. For instance avoiding remnant pillars, longwall face configurations and mining away from, rather than towards, a major weakness plane were strategic approaches based on experience and observation.

A more scientific approach became available with the introduction of energy balance equations to mining operations. The concept of energy release rate was introduced based on the premise that if the released energy could be reduced, the seismic events would be starved of energy. Although this reasoning was found to be erroneous (Salamon, 1983), a strong empirical correlation was found between energy release rate, frequency, magnitude and damage of rockbursts for the South African gold mines. These concepts were incorporated into computer models which allowed comparison of energy release rate for different mining layouts and sequence of extraction.

The energy balance equations also showed that the one parameter over which the mining engineer had any control was the volumetric closure in a stope. If the closure could be reduced, then all the energy components were reduced. Backfill or other support systems between hanging wall and footwall both limit stope closure and absorb energy otherwise liberated as seismic energy. In recent years large permanent stabilizing pillars have been left at

regular intervals to reduce stope closure in thin tabular deposits, such as the gold mines in South Africa and at a uranium mine in Elliot Lake, Ontario. Especially in South Africa it has been shown that these stabilizing pillars reduce the frequency and magnitude of seismic events.

The benefits of the strategic techniques are only realized in the long-term.

ROCKBURST ALLEVIATION

Morrison, R.G.K., (1942), Report on the rockburst situation in Ontario mines; Trans CIM, vol. 45, pp. 225-272.

Cook, N.G.W., (1967), The design of underground excavations; 8th U.S. Rock Mech. Symp., Minnesota, pp. 167-193.

Hodgson, K. and Joughin, N.C., (1967), The relationship between energy release rate, damage and seismicity in deep mines; 8th U.S. Rock Mech. Symp., Minnesota, pp. 194-209.

Waddell, G., (1970), Progress on techniques of investigating and controlling rockbursts; Trans. AIME, vol. 247, pp. 186-192.

Salamon, M.D.G., (1974), Rock mechanics of underground excavations; 3rd Congr. Int. Soc. Rock Mech., Denver, Colorado, vol. 1, Part B, pp. 951-1099.

Board, M.P. and Crouch, S.L., (1975), Mine planning to control rockbursts in cut-and-fill excavations; 15th U.S. Rock Symp., Minnesota.

Ortlepp, W.D. and Steele, K.E., (1975), Rockbursts: the nature of the problem and management countermeasures at ERPM Ltd.; Proc. S. Afr. Assoc. of Mine Managers, pp. 225-278.

Hiramatsu, Y., Maebashi, J. and Oka, Y., (1977), Controlling rock burst hazard on mining the steeply inclined copper ore bed in the Besshi mine; 6th Int. Strata Control Conf., Banff, Canada.

High Level Committee, (1977), An industrial guide to the amelioration of the hazard of rockbursts and rockfalls; Research Organization, Chamber of Mines of South Africa, 178 p.

Salamon, M.D.G. and Wagner, H., (1979), Role of stabilizing pillars in the alleviation of rockburst hazard in deep mines; 4th Congr. Int. Soc. Rock Mech., Montreaux, vol. 2, pp. 561-566.

Heunis, R., (1980), The development of rockburst control strategies for South African gold mines; J. S. Afr. Inst. Min. Met, pp. 139-149.

Deline, E.P. and Gay, N.C., (1982), The influence of stabilizing pillars on seismicity at ERPM; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 257-264.

Tanton, J.H., McCarthy, T.F. and Hagen, T.O., (1982), The introduction of stabilizing pillars to reduce rockbursts at Western Deep Levels Limited; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met Symp. Series No. 6, pp. 245-252.

Van Antwerpen, H.E.F. and Spengler, M.G., (1982), The effect of mining-related seismicity on excavations at East Rand Proprietary Mines, Limited; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met Symp. Series No. 6, pp. 235-244.

Russell, F.M., Armstrong, D.R.M. and Talbot, R., (1983), Analysis of stoping sequence and support requirements in a high stress environment - ZCCM - Mufulira Division; Rockbursts: Prediction and Control, IMM, London, pp. 161-173.

Salamon, M.D.G., (1983), Rockburst hazard and the fight for its alleviation in South African gold mines; Rockbursts: Prediction and Control, IMM, London, pp. 11-36.

CONTROLLING ROCKBURST DAMAGE AND DESTRESSING

The tactical approach to rockburst alleviation is to accept that some rockbursting is inevitable, but seeks either to limit the extent or the timing of the damage.

The peak particle velocity is the cause of the damage to conventional support systems which usually tend to be rigid. This led to the development of rapid-yielding support systems in South African gold mines of which the rapid-yielding hydraulic prop is a good example. In access drifts the concept of lacing was introduced which consists of mild steel grouted rebar, wire mesh and flexible steel cable over the mesh and connected to the rebars in a diamond pattern. It was found that this type of support system, when subjected to a nearby rockburst, allowed the wall rocks to rapidly converge inwards while still maintaining the integrity of the drift. Friction type (e.g., spit sets and swellex) support systems with wire mesh have been found to be effective in rockburst conditions in Canadian mines.

Although some form of destress blasting was practised in the Kirkland Lake mining camp in the 1940's, the first systematic destressing trials took place on longwall faces in South African gold mines in the 1950's. Although initial results were encouraging the practice was discontinued when it was found that no excess energy was being released other than that of the explosive. However, destress blasting was continued in North American mines (Coeur d'Alene, Red Lake, Sudbury and Kirkland Lake) with apparent success.

The concept of destressing is to fracture highly stressed pillars with explosives thereby reducing the deformation modulus and the stress they can support. This in turn allows the hanging wall and footwall to converge with the resultant change in potential energy. In many mines, rockbursts occur shortly after destress blasts and large production blasts, due to stress

transfer. In some cases it may be possible to control the timing of a rockburst by such blasting.

The benefits of these tactical techniques are realized in the short-term.

SUPPORT SYSTEMS

Margo, E. and Bradley, R.K.O., (1966), An analysis of the load compression characteristics of conventional packs; J. S. Afr. Inst. Min. Met., vol. 66, pp. 364-401.

Ortlepp, W.D., (1970), An empirical determination of the effectiveness of rockbolt support under impulse loading; Proc. Int. Symp. Large Permanent Underground Openings, Oslo, pp. 197-205.

Ortlepp, W.D., More O'Ferrall, R.C. and Wilson, J.W., (1972/73), Support method in tunnels; Assoc. Mine Managers S. Africa, Papers and Discussions, pp. 167-196.

Tyser, J.A. and Wagner, H. (1976/77), Review of six years of operations with the extended use of rapid-yielding hydraulic props at the East Rand Proprietary Mines, Limited and experience gained throughout the industry; Assoc. Mine Managers S. Africa, Papers and Discussions, pp. 321-347.

Fernandez, L.M. and Van Der Heever, P.K., (1982), Ground movement and damage accompanying a large seismic event in the Klerksdorp district; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 193-198.

Wagner, H., (1982), Support requirements for rockburst conditions; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 209-218.

Hedley, D.G.F. and Whitton, N., (1983), Performance of bolting systems subject to rockbursts; CIM Seminar, Underground Support Systems, Sudbury.

Lampl, F., (1983), Effect and limitations of abnormal loads on roof supports;

Rockbursts; Prediction and Control, IMM, London, pp. 123-132.

Ortlepp, W.D., (1983), Considerations in the design of support for deep hard-rock tunnels; 5th Congr. Int. Soc. Rock Mech. Melbourne.

Ortlepp, W.D., (1983), The design of mine tunnels and the selection of support; Chapter 4: Rock Mechanics in Mining Practice, S. Budavari (Editor), S. Afr. Inst. Min. Met., Mono Series No. 5, pp. 77-104.

Russell, F.M., Armstrong, D.R.M. and Talbot, R. (1983), Analysis of stoping sequence and support requirements in a high stress environment - ZCCM - Mulfulira Division; Rockbursts: Prediction and Control, IMM, London, pp. 161-173.

Wagner, H., (1983), Principles of the support of tabular excavations; Chapter 7, Rock Mechanics in Mining Practice, S. Budavari (Editor), S. Afr. Inst. Min. Met., Mono Series No. 5, pp. 151-172.

Emere, G.T.G., (1984), Stope support technology development; World Mining Equipment, Jan. 1984.

More O'Ferrall, R.C., (1984), Support techniques in gold mine tunnels; World Mining Equipment, Jan. 1984.

Ortlepp, W.D., (1985), The design of support for rockburst-prone tunnels; CIM Seminar on Rockbursts, Sudbury.

DESTRESS BLASTING

Roux, A.J.A., Denkhaus, H.G. and Leeman, E.R., (1956), The stresses in and the condition of the ground around mine excavations; Trans. CIM, vol. 49, No. 525.

Roux, A.J.A., Leeman, E.R. and Denkhaus, H.G., (1957), Destressing: a means of ameliorating rockburst conditions. Part I: the conception of destressing and results obtained from its application; J. S. Afr. Inst. Min. Met., October 1957, pp. 101-127.

Part II: Hill, F.G. and Plewman, R.P., Implementing destressing with a discussion on the results so far obtained; J. S. Afr. Inst. Min. Met., December 1957, pp. 256-268.

Denkhaus, H.G., Hill, F.G. and Roux, A.J.A., (1959), Review of research into rockbursts and strata movement in deep level mining in South Africa; Bull. Inst. Min. Met., April 1959.

Moruzi, G.A. and Pasieka, A.R., (1964), Evaluation of a blasting technique for destressing ground subject to rockbursting; 6th U.S. Rock Mech. Symp., Rolla, Missouri.

Cook, N.G.W., Hoek, E., Pretorius, J.P.G., Ortlepp, W.D. and Salamon, M.D.G., (1946), Rock mechanics applied to rockbursts; J. S. Afr. Inst. Min. Met., May 1966, pp 435-528.

Blake, W., (1972), Rock-burst mechanics; Quarterly Colorado School of Mines, vol. 67, No. 1.

Blake, W., (1972), Destress test at the Galena mine; Trans. SME-AIME, vol. 252.

Crouch, S.L., (1974), Analysis of rock bursts in cut-and-fill stopes; Trans. SME-AIME, vol. 256, pp. 298-303.

Karwoski, W.J., McLaughlin, W.C. and Blake, W., (1979), Rock preconditioning to prevent rock bursts - report on a field demonstration, USBM, RI 8381.

Corp, E.L., (1981), Rock mechanics research in the Coeur d'Alene mining district; Conf. Application Rock Mech. to Cut and Fill Mining; Lulea, Sweden, Pub. by IMM, pp. 40-48.

Blake, W., (1982), Destressing to control rockbursts; Underground Mining Methods Handbook, AIME, Sec. 7, pp. 1535-1539.

Blake, W., (1982), Rock preconditioning as a seismic control measure in mines: Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met.,

Symp. Series No. 6.

Garrood, P.S., (1982), Ground control aspects of the development at Creighton No. 11 shaft; 14th Can. Rock Mech. Symp., Vancouver.

Board, M.P. and Fairhurst, C., (1983), Rockburst control through destressing - a case example; Symp. Rockbursts: Prediction and Control, IMM, London, pp. 91-102.

Cook, J.F. and Bruce, D., (1983), Rockbursts at Macassa Mine and the Kirkland Lake mining area; Symp. Rockbursts: Prediction and Control, IMM, London, pp. 81-90.

Newmann, M., Makuch, A., Hedley, D.G.F. and Blake, W., (1987), Practical applications of pillar destressing at Campbell Red Lake Mine; CIM 8th Underground Operators Conf., Elliot Lake, February 1987.

ROCKBURST PREDICTION

There are two components to rockburst prediction: location and time. At many mines microseismic systems indicate those areas of the mine which are rockburst-prone and a build up in microseismic activity sometimes precedes a large rockburst. Computer models also indicate locations which are highly stressed and rockburst-prone. However, consistent prediction of time has been much more elusive.

Some of the precursor phenomena that have been evaluated include, microseismic count rate, average energy per seismic event, and change in waveform frequencies.

Much of the original research on rockburst prediction was done by the United States Bureau of Mines. In recent years a large research effort has been underway at Western Deep Levels in South Africa.

ROCKBURST PREDICTION

Obert, L., (1941), Use of subaudible noise for prediction of rock bursts; U.S. Bureau of Mines, RI 3555.

Obert, L. and Duvall, W.I., (1957), Microseismic method of determining the stability of underground openings; U.S. Bureau of Mines, Bull. 573.

Armstrong, B.H., (1969), Acoustic emission prior to rockbursts and earthquakes, Bull. Seis. Soc. Am., vol. 59, No. 3, pp. 1259-1279.

Brady, B.T., (1974), Seismic predictors before rock failure in mines; Nature, vol. 252, No. 5484, pp. 549-552.

Brady, B.T. and Leighton, F.W., (1977), Seismicity anomaly prior to a moderate rock burst: a case study; Int. J. Rock Mech. Min. Sci & Geomech. Abst., vol. 14, pp. 127-132.

Brink, A.V.Z., (1978), Rockburst prediction in South African gold mines; 2nd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.

Langstaff, J.T., (1980), Interpretation of acoustic emission data - Star Mine; 2nd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.

Blake, W., (1981), Evaluation of some rockburst precursor phenomena; 3rd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.

Brink, A.V.Z., (1981), and O'Connor, D., (1981), Rockburst prediction research - development of a practical early warning system; 3rd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.

Brink, A.V.Z. and Mountfort, P.I., (1982), Feasibility studies on the prediction of rockbursts at Western Deep Levels; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 317-325.

Leighton, F.W., (1982), Microseismic monitoring and warning of rockbursts;

Rockbursts and Seismicity in Mines, Johannesburg, S.Afr. Inst. Min. Met. Symp. Series No. 6, pp. 287-196.

McDonald, A.J., (1982), Radon gas emissions and seismicity in deep level gold mines; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 309-316.

Stopinski, W. and Dnowska, R., (1982), Rock resistivity in the Lubin (Poland) copper mine and its relation to variations of strain field and occurrences of rockbursts; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 297-308.

Walsh, J.B., (1982), Precursors to rock failure observed in laboratory experiments; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 269-276.

Mountfort, P.I. and Brink, A.V.Z., (1985), Microseismic activity preceding rockbursts observed at Western Deep Level Gold Mine; 4th Conf. Acoustic Emission/Microseismic Activity, Penn. State University.

CASE HISTORIES

CANADA

Christian, J.D., (1939), Rockbursts at Teck-Hughes Mine; Trans. CIM, Vol. 42, pp. 550-567.

Robertson, A.F. (1939), Rockbursts at Wright-Hargreaves Mine; Trans. CIM, vol. 42, pp. 583-592.

Robson, W.T., Adamson, J.C. and Selnes, W.E., (1940), Rockbursts at Lake Shore Mines; Trans. CIM, vol. 43, pp. 7-30.

Hopkins, H., (1940), Faulting at the Wright-Hargreaves Mine with notes on ground movement; Trans. CIM, vol. 43, pp. 685-707.

Morrison, R.G.K., (1942), Report on the rockburst situation in Ontario mines;

- Trans CIM, vol. 45, pp. 225-272.
- Robson, W.T., (1946), Rockburst incidence, research and control measures at Lake Shore Mines, Ltd.; Trans. CIM, vol. 49, pp. 367-376.
- Dickhout, M.H., (1957), Rockburst control at the Creighton Mine of the International Nickel Company of Canada, Limited; 6th Commonwealth Min. & Met. Congr., Canada, pp. 385-390.
- Robson, W.T., Selnes, W.E. and Seymour, M.E., (1957), Rockburst control measures at Lake Shore Mines, Limited; 6th Commonwealth Min. & Met. Congr., Canada, pp. 376-384.
- Carter, G.F. and Hilgendorf, C.G., (1963), Illustrations of rock pressure effects at McIntyre Porcupine Mines Ltd.; 2nd Can. Rock Mech. Symp., Queen's University, Kingston, pp. 97-114.
- Buckle, F., (1964), The rockburst hazard in Wright Hargreaves Mine at Kirkland Lake; National Safety Congr., Chicago.
- Oliver, P.H., (1975), Ground control in transverse cut-and-fill mining operations at INCO; 10th Can. Rock Mech. Symp., Queen's University, Kingston, vol. 2, pp. 1-27.
- Jeremic, M.L. (1982), Shaft in rockburst zone Cu-Ni Thierry Mine, Canada; Proc. Australas. Inst. Min. Metal. No. 281, pp. 15-21.
- Cook, J.F. and Bruce, D., (1983), Rockbursts at Macassa Mine and the Kirkland Lake mining area; Rockbursts: Prediction and Control, IMM, London, pp. 81-90.
- Hedley, D.G.F., Roxburgh, R.W. and Muppalaneni, S.N., (1984), A case history of rockbursts at Elliot Lake; 2nd Int. Conf. Stability in Underground Mines, Lexington, Kentucky.
- Hedley, D.G.F., Neumann, M., Makuch, A. and Blake, W., (1985), Rockbursts at Campbell Red Lake Mine; CIM Rockburst Seminar, Sudbury, Ontario.

Hedley, D.G.F., Bharti, S., West, D. and Blake, W., (1985), Fault-slip rockbursts at Falconbridge Mine; 4th Conf. Acoustic Emission/Microseismic Activity, Penn. State University.

Hedley, D.G.F. and Wetmiller, R.J., (1985), Rockbursts in Ontario mines during 1984; CANMET Report SP85-5, Energy, Mines and Resources Canada.

Oliver, P.H., (1985), Creighton Mine, July 6, 1984 rockburst; CIM Rockburst Seminar, Sudbury, Ontario.

West, D., (1985), A case history of rockbursts at Falconbridge Mine; CIM Rockburst Seminar, Sudbury, Ontario.

Hedley, D.G.F., (1986), Condition of the hanging wall above the rockburst area at Quirke Mine; Division Report 86-155(TR), CANMET, Energy, Mines and Resources Canada.

UNITED STATES

Crane, W.R., (1929), Rock bursts in the Lake Superior copper mines, Keweenaw Point, Mich; U.S. Bureau of Mines, Bull. 309.

Blake, W., (1972), Rock-burst mechanics; Colorado School of Mines Quarterly, vol. 67, No. 1.

Blake, W., (1972), Destress test at the Galena Mine; Trans. SME-AIME, vol 252.

Brady, B.T. and Leighton, F.W., (1977), Seismicity anomaly prior to a moderate rock burst; Int. J. Rock Mech. Min. Sci. & Geomech. Abst., vol. 14, pp. 127-132.

Leighton, F.W., (1978), Microseismic studies at the Henderson Mine; 2nd Conf. Acoustic Emission/Microseismic Activity, Penn. State University.

Korwoski, W.J., McLaughlin, W.C. and Blake, W., (1979), Rock preconditioning

to prevent rock bursts - report on a field demonstration; U.S. Bureau of Mines, RI 8381.

Corp. E.L., (1981), Rock mechanics research in the Coeur d'Alene mining district; Conf. Application Rock Mech. to Cut-and-Fill Mining, Lulea, Sweden, Pub. IMM, pp. 40-48.

Leighton, F.W., (1981), A case history of a major rock burst; U.S. Bureau of Mines, RI 8701.

Bush, D.D., Blake, W., and Board, M.P., (1982), Evaluation and demonstration of underhand stoping to control rock bursts; U.S. Bureau of Mines, Contract Report 62-85.

Board, M.P. and Fairhurst, C., (1983), Rockburst control through destressing - a case example; Rockbursts: Prediction and Control, IMM, London, pp. 91-102.

SOUTH AFRICA

Hill, F.G., (1954), An investigation into the problem of rock bursts. An operational research project. Part I: The approach to the problem and analysis of the rock bursts that have occurred on the ERPM during the years 1948-1953; J. Chem. Met. Min. Soc. S. Afr., Oct. 1954, pp. 63-83. Part II: Roux, A.J.A. and Denkhaus, H.G., An analysis of the problem of rock bursts in deep level mining; Ibid., Nov. 1954, pp. 103-120.

Denkhaus, H.G., Hill, F.G. and Roux, A.J.A., (1959), Review of research into rockbursts and strata movement in deep level mining in South Africa; Bull. IMM, April 1959.

Hodgson, K. and Joughin, N.C., (1967), The relationship between energy release rate, damage and seismicity in deep mines; 8th U.S. Rock Mech. Symp., Minnesota, pp. 194-209.

Pretorius, P.G.D., (1972/73), Strata control and rockburst problems on central Witwatersrand gold mines; Assoc. Mine Managers S. Afr., Papers and

Discussions, pp. 481-520.

- Ortlepp, W.D. and Steele, K.E. (1975), Rockbursts: the nature of the problem and management countermeasures at ERPM Ltd; Proc. S. Afr. Assoc. Mine Managers, pp. 225-278.
- Salamon, M.D.G. and Wagner, H., (1979), Role of stabilizing pillars in the alleviation of rockburst hazard in deep mines; 4th Congr. Int. Soc. Rock Mech., Montreaux, vol. 2, pp. 561-566.
- Deline, E.P. and Gay, N.C., (1982), The influence of stabilizing pillars on seismicity at ERPM; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 257-264.
- Fernandez, L.M. and Van Der Heever, P.K., (1982), Ground movement and damage accompanying a large seismic event in the Klerksdorp district; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 193-198.
- Lawrence, A., (1982), Seismicity in the Orange Free State gold mining district; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 121-130.
- Ortlepp, W.D., (1982), Rockbursts in South African gold mines: a phenomenological view; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 165-178.
- Spottiswoode, S.M., (1982), Source mechanisms of mine tremors at Blyvooruitzicht Gold Mine; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 29-38.
- Tanton, J.H., McCarthy, T.F. and Hagan, T.O., (1982), The introduction of stabilizing pillars to reduce rockbursts at Western Deep Levels, Limited; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 245-252.
- Van Antwerpen, H.E.F. and Spengler, M.G., (1982), The effect of mining-related

seismicity on excavations at East Rand Proprietary Mines, Limited; Rockbursts and Seismicity in Mines, Johannesburg, S. Afr. Inst. Min. Met. Symp. Series No. 6, pp. 235-244.

Joughin, N.C. and Jager, A.J., (1983), Fracture of rock at stope faces in South African gold mines; Rockbursts: Prediction and Control, IMM, London, pp. 53-66.

INDIA

Jones, J.S., (1927/28), Discussion of Crowle, P., Notes on ground movement and methods of support in deep mining, Kolar Gold Field; Min. Met. Soc., vol. 4, No. 22.

Spalding, J., (1947), Deep mining problems in the Kolar Gold Field; Eng. Min. J., August 1947, pp. 70-75.

Cowlin, W.R. and Isaacson, E. de St. Q., (1959), Planning and research necessitated by rockbursts in an underground shaft; Mine and Quarry Eng., Feb. 1959, pp. 75-81.

Taylor, J.T.M., (1963), Research on ground control and rockbursts on the Kolar Gold Field, India; Trans. IMM, vol. 72, pp. 317-338.

Krishna Murthy, R., (1972), A review of rockburst research in the Kolar Gold Fields; Symp. on Rock Mech. - Theory and Practice, Dhanbad, India.

Krishna Murthy, R. and Gupta, P.D., (1983), Rock mechanics studies on the problem of ground control and rockbursts in the Kolar Gold Fields; Rockbursts: Prediction and Control, IMM, London, pp. 67-80.